Reducing Uncertainty of Nonpoint Source Nutrient Pollution Management Strategies with Adaptive Management

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Abstract

Nonpoint source (NPS) pollution is emerging as a critical water quality issue. Nonpoint sources are increasingly recognized both as causes of impairment and as presenting potential mitigation opportunities. However, due to the diffuse nature of NPS stressors, NPS loads are extremely complicated to model. For similar reasons, the benefits of NPS pollution reduction measures on receiving water bodies are also difficult to quantify. Governments need to manage NPS water pollution while they acquire better information about its sources and the effectiveness of various NPS pollution control strategies. Adaptive management is an approach to environmental management that enables environmental problems to be dealt with in the short term while uncertainty is reduced over the long term. Adaptive management is a promising way to address water quality impairments due partially or wholly to nonpoint sources. This paper describes how uncertainty currently inherent in the management of NPS pollution can be reduced through utilization of an adaptive management approach.

The case examined is the development of nitrogen and phosphorous Total Maximum Daily Loads for the Upper New Hope Creek Arm of Jordan Lake, a reservoir in the Triangle region of North Carolina. The Upper New Hope Arm nutrient loads are largely from nonpoint sources, and there is significant uncertainty about the exact amounts of the loads and the degree that NPS control measures can be expected to reduce them. Jordan Lake stakeholders have broached the topic of using an adaptive approach to manage nonpoint sources in the Upper New Hope Arm. However, the component most crucial to an adaptive management strategy, a water quality monitoring network that will enable assessment of the management strategy, has not yet been drafted. Additional data that link water quality conditions to pollution prevention practices are needed to evaluate management modules and achieve water quality improvements efficiently.

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Introduction

Nonpoint source (NPS) pollution is emerging as a critical water quality issue, particularly as states develop Total Maximum Daily Loads (TMDLs) for waters deemed impaired according to the federal Clean Water Act. A TMDL is the numeric translation of the assimilative capacity of a given water body, designed to protect its designated uses and meet applicable water quality standards (NCDWQ, 2000). This value can be used as a benchmark to assess the effects of quantities of specific pollutants that contribute to water quality stressors.

Nonpoint sources are increasingly recognized as both causes of impairment and as presenting potential mitigation opportunities. However, due to the diffuse nature of NPS pollution from multiple land uses, NPS loads are extremely complicated to model. For similar reasons, the benefits of NPS pollution control measures on receiving water bodies are also difficult to quantify. Governments need to manage NPS water pollution while they acquire better information about its sources and the effectiveness of various NPS pollution control strategies. A valuable paradigm for reducing the uncertainty of NPS pollution is adaptive management.

The National Research Council's Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction has applied the term adaptive implementation to TMDL development. According to the Committee, "Adaptive implementation simultaneously makes progress toward achieving water quality standards while relying on monitoring and experimentation to reduce uncertainty" (NRC, 2001). (Adaptive implementation and management both refer to a process of evaluating, revising, and re-implementing the management strategy, and the terms are used interchangeably in this work.) An important and under-emphasized aspect of the adaptive management process is that the management strategy is changed *in response to* the results of a quantitative analysis of responses in the environmental system over time. Utilizing an adaptive approach to water quality management can reduce the uncertainty that has often hindered NPS pollution control.

The Upper New Hope Creek Arm of Jordan Lake in the Triangle region of North Carolina is developing TMDLs for nitrogen and phosphorous to address nonattainment of North Carolina chlorophyll *a* standards for drinking water and habitat uses. Nutrient loads are largely from nonpoint sources (Tetra Tech, 2003), and there is significant uncertainty about the exact amounts of the loads and the degree to which NPS control measures can be expected to reduce them. Aspects of adaptive management have been proposed for the management strategy, such as initiating monitoring enhancements early in the planning process (Miller, 2004). However, the overall management strategy cannot be characterized as "adaptive" because a procedure for linking the evaluation of water quality data with the revision of the management strategy has not yet been established. Unless this deficiency is remedied, evaluations of the management strategy are likely to measure administrative outcomes rather than improvements achieved in water quality.

NPS pollution control strategies that use adaptive management would analyze responses in impaired water bodies in conjunction with particular management strategies. To be adaptive in the sense of reducing uncertainty, these analyses must be used to design future management strategies. Future strategies should draw on observational evaluation of the measures found to be most effective in the particular watershed. The management of information on pollution controls and watershed responses must also be improved to enable revisions of management strategies. Because adaptive approaches are more efficient than less-coordinated approaches, utilizing adaptive management would help maximize returns on investments in ambient water quality improvements.

Total Maximum Daily Loads

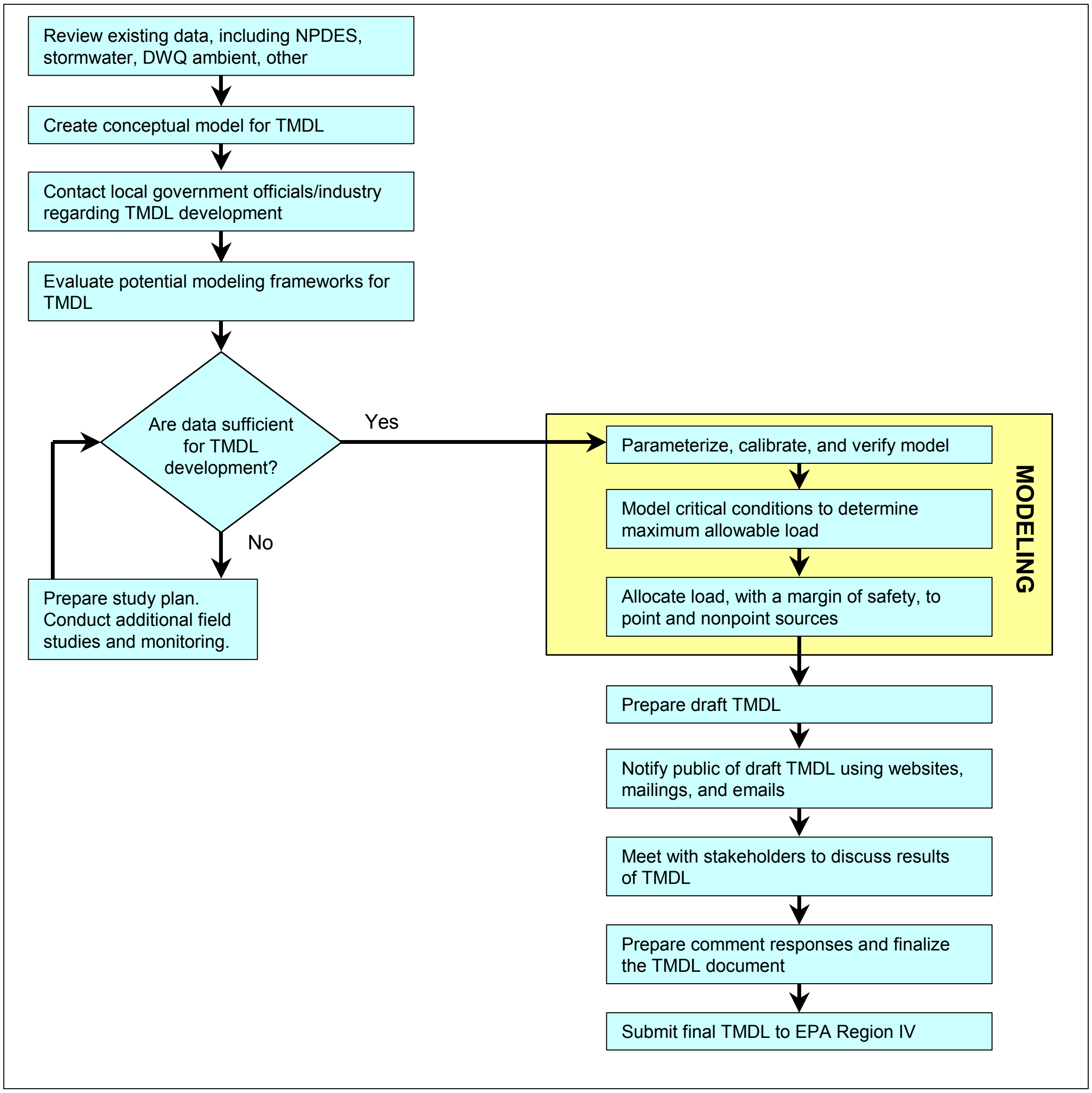
Ambient water quality planning takes place largely through the provisions of section 303(d) of the Clean Water Act of 1972, [1] which requires creation of TMDLs for impaired waters. Waters are deemed impaired if they do not sufficiently provide for their designated uses or if they do not meet applicable water quality standards. The act contained provisions for protection of fish, shellfish, and wildlife and set forth the recreation-based goal that all waters of the United States should be "fishable and swimmable."

Under section 303(d) of the Clean Water Act, waters not meeting water quality standards are to be listed in a statewide inventory. Each state is to establish TMDLs for each identifiable pollutant believed to be responsible or partly responsible for impairing each water body. According to the Clean Water Act section 303(d), a given TMDL "shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality" (33 USC 1313(d)). A TMDL is a limit on the total load of a given pollutant that may be discharged into a given water body with a margin of safety to account for uncertainty in the analysis. The TMDL for a given pollutant supersedes any lower water quality standard.

Figure 1 is a flow chart of the basic TMDL development process once the impairment has been declared. The process is the same regardless of the pollutant or its sources.

[1] Originally known as the Federal Water Pollution Control Act of 1948.

Figure 1. Flowchart for freshwater TMDL development (modified from NCDWQ, no date).



After the TMDL is established, the total load is divided into a waste load allocation, a load allocation, and a margin of safety, which includes statistical uncertainty and/or natural variation. The allocation equation is often denoted as

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS}.$$

The waste load allocation is the total amount of the pollutant that discharge permit holders can contribute to that water body. The load allocation is the amount that may be delivered from all nonpoint sources, including background sources. Sometimes, background sources are accounted for separately from anthropogenic NPS loads, and the allocation equation is then written as

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{Background} + \text{MOS}.$$

This differentiation simplifies analysis of the load allocation because attainment of the load allocation is then ostensibly entirely dependent upon the NPS management strategy (as long as the margin of safety adequately accounts for natural variability).

USEPA does not currently require the margin of safety to be based on an uncertainty analysis. In fact, sometimes conservative assumptions are used instead of a margin of safety. Environmental engineer William Walker (2003) has helped clarify the margin of safety by defining the allocation equation

$$TMDL = \sum WLA + \sum LA + Background + MOS$$

more specifically as a margin of variability plus a margin of uncertainty:

$$TMDL = \sum WLA + \sum LA + Background + MOV + MOU.$$

"Variability" refers to the stochastic nature of data on the environmental system; it is, in Walker's words, "insensitive to management measures." "Uncertainty," on the other hand, is a product of data limitations and the inherently reductionistic nature of modeling. According to Walker (2003), "unlike variability, uncertainty can be reduced in many cases by collecting additional data and improving forecast models under an adaptive management framework." Although this distinction is helpful, the margin of variability must be determined statistically and therefore has uncertainty of its own.

After allocations have been determined, an implementation plan is created. According to USEPA guidance on developing nutrient TMDLs (1999),

> The TMDL implementation plan must include the following (§ 130.33(b)(10))
> • A description of the control actions and/or management measures which will be implemented to achieve the wasteload allocations and load allocations, and a demonstration that the control actions and/or management measures are expected to achieve the required pollutant loads;
> • A time line, including interim milestones, for implementing the control actions and/or management measures, including when source-specific activities will be undertaken for categories and subcategories of individual sources and a schedule for revising NPDES permits;
> • A discussion of your reasonable assurances, as defined at 40 CFR §130.2(p), that wasteload allocations and load allocations will be implemented;
> • A description of the legal [mechanisms] under which the control actions will be carried out;
> • An estimate of the time required to attain and maintain water quality standards and discussion of the basis for that estimate;
> • A monitoring and/or modeling plan designed to determine the effectiveness of the control actions and/or management measures and whether allocations are being met;
> • A description of measurable, incremental milestones for the pollutant for which the TMDL is being established for determining whether the control actions and/or management measures are being implemented and whether water quality standards are being attained; and
> • A description of [the] process for revising TMDLs if the milestones are not being met and projected progress toward attaining water quality standards is not demonstrated.

The implementation strategy functions as partly as a contract and partly as a plan. It is a legal document that can be binding on regulated parties, and it also specifies the means of achieving the TMDL. Unfortunately, there are so many sources of uncertainty from both natural and social systems that even well-designed and implemented TMDL plans cannot guarantee use attainment (NRC, 2001).

Challenges in Developing TMDLs

States and the USEPA largely ignored the Clean Water Act's TMDL provisions until the late 1990s, when public interest organizations began to sue the states and USEPA on the basis of noncompliance with section 303(d). When the USEPA and states did begin to develop TMDLs, implementation plans focused mostly on regulating end-of-pipe discharges by designating segments as limited by water quality standards, not effluent standards. Significant strides were achieved in ambient water quality because of this approach (NRC, 2001).

Recently, nonpoint sources have become significant obstacles to meeting the goals of the Clean Water Act. Possible sources of NPS pollution are numerous and diverse, including stormwater runoff, forestry, agriculture, residential development, septic systems, and mining activities. NPS pollution can also be transported great distances by precipitation runoff (rainfall or snowmelt). In-ground, in-stream, and in-lake processes such as nutrient uptake and sedimentation can affect concentrations of nutrients in receiving water bodies. Consequently, quantifying NPS pollution is a difficult task for the USEPA and states.

States are supposed to study impairments by watershed, rank impaired waters by priority, and develop TMDLs for the most critical water bodies first (USEPA, 1994). Under 1992 USEPA rules, states should develop TMDLs for impaired water bodies within 8 to 13 years of their impairment determinations and 303(d) listings. Unfortunately, some states have developed TMDLs based on ease of study, not priority, due to lack of guidance, resources, or time (USGAO, 2000). TMDLs are generally easier to develop when point sources constitute the bulk of the problem, partly because major discharge permits are subject to effluent limits and require monitoring downstream of the discharge under USEPA rules for the National Pollution Discharge Elimination System (NPDES).

States tend to focus monitoring efforts on areas that are suspected *a priori* to have impairments due to human activities, but areas of intense human activity do not necessarily coincide with water quality impairments (USGAO, 2000; NRC, 2001). Therefore, there may be waters that are impaired but not listed because they are not being monitored. Some states have also found water bodies that were mistakenly listed and were shown by additional monitoring not to be impaired (USGAO, 2000). This indicates that the most basic information to simply assess the scope of the national water pollution problem is insufficient.

Determining which nonpoint sources are responsible for how much NPS pollution can be a complicated and therefore costly step in developing a TMDL. If point sources are only a small portion of the total load, data may not even be sufficient to estimate the actual current load. If data on an impaired water body are not sufficient to develop a TMDL, states are supposed to create study plans to obtain sufficient information within a specified period of time. Additional data to develop TMDLs are often necessary because models must be calibrated and have boundary conditions set based on observational data from actual samples. If sophisticated models are necessary, as is often the case to assess NPS pollution, data needs for model calibration and verification are even greater.

Challenges in Quantifying Pollution from Nonpoint Sources

In 1999, the Subcommittee on Water Resources and Environment in the House of Representatives asked the United States Government Accounting Office (GAO) to report on whether states have sufficient data to list water quality impairments and develop TMDLs. The GAO conducted a survey that confirmed that states are much better positioned to identify point sources of pollution than nonpoint sources. In the survey, the "vast majority of states reported that they do not have much of the data they need to address nonpoint sources of pollution" (USGAO, 2000).

This lack of knowledge has been partly responsible for states' and the USEPA's delay in addressing NPS pollution. At present, USEPA guidance on designing NPS management strategies to achieve TMDLs with "reasonable assurance" is vague and generally deficient (USGAO, 2000). Technical assistance to states and tribes is also lacking or merely ad-hoc (USGAO, 2000). North Carolina's Division of Water Quality (NCDWQ) admits that, because of the diffuse nature of NPS pollution, "it is difficult and resource intensive to quantify nonpoint source pollution contributions to water quality degradation in a given watershed" (NCDWQ, 2000). In a memorandum commenting on proposed changes to Clean Water Act rules, the State of New York has argued that requiring TMDLs for waters impaired only from NPS pollution "would place an unmanageable strain on limited resources, while, in most cases, providing little if any benefit" (NYSDEC, no date).

Uncertainty in the TMDL can be addressed in two non-exclusive ways: use of conservative assumptions and estimation of the margin of safety. Due to the indistinct nature of the nonpoint sources and the high degree of uncertainty in NPS load estimates, the TMDL margin of safety is often as high as 20%, and sometimes more (NYCDEP/NYSDEC, 2001). A large margin of safety leaves a smaller load available for allocation between point and nonpoint sources, which increases the total costs of control measures that will be needed to achieve the TMDL. Yet, USEPA currently does not require the margin of safety to be established on the basis of an uncertainty analysis (Ehlers, 2001).

Creating a plan to achieve load reductions that is agreeable to all stakeholders in such a situation can be difficult. Point source dischargers, who must already meet technology-based discharge standards, may reasonably argue that they have already taken on a fair share of load reductions. Yet, the question of who should be responsible for managing loads and reductions from nonpoint sources is usually far from clear. NPS pollution is by definition diffuse in nature; often, contributions come from ordinary land use activities, such as agriculture or residential uses. Regulation of such widespread activities affects a large portion of the population, which may demand a high level of certainty before agreeing to bear higher economic costs associated with more abatement measures.

In the case of Pronsolino et al. v. Marcus and Browner (2000), the Northern California District Court held that USEPA can withdraw funding from a state if NPS controls required by a TMDL are not implemented (Novotny, 2003). The court also held that nonpoint sources must be considered in the creation of a TMDL if they are a factor in the impairment under consideration, and in this case they were the sole cause of impairment (Pronsolino et al. v. Marcus and Browner, 2000). The court noted that TMDLs are to be set at levels that "implement" water quality standards, and that "it would have been impossible to do so without taking any nonpoint sources into account as well as any point sources." Furthermore, "to have limited TMDLs only to point-source loadings… would have left state agencies guessing at how to allocate the burden of cleanup between point and nonpoint sources of the same pollutant."

Unfortunately, many states find themselves in exactly this quandary. There is no pre-defined way to allocate pollutant loads; portion of total load is only one of several methods. For instance, even if discharge permit-holders have already been subjected to increasingly stringent effluent standards, which is often the case, the first allocation method considered is often to make them responsible for reducing the same proportional share of a given pollutant load because technology-based controls have more certain outcomes (NRC, 2001). Other concerns, such as cost, secondary benefits, funding availability, local interest, political feasibility, or ease of enforcement might also be considered when deciding how to allocate the reductions required to achieve the TMDL (NYCDEP/NYSDEC, 2001).

Whether a given management strategy will be responsible for any improvements observed in a given impaired water body can also be highly debatable. Separating natural from anthropogenic trends requires historical water quality data that are often not available at a quality or quantity that is sufficient to make such a determination. However, planners and resource managers will be asked to make that determination when the strategies proposed place additional abatement costs on the public or the private sector. Scientific evidence that the chosen management strategy is likely to be effective to some reasonable degree would greatly contribute to the fulfillment of this duty.

Adaptive Management

Adaptive management is emerging as a promising means of addressing and reducing the uncertainties inherent in environmental management processes. Nyberg (1999) describes adaptive management as

> a formal, systematic, and rigorous approach to learning from the outcomes of management actions, accommodating change and improving management. It involves synthesizing existing knowledge, exploring alternative actions and making explicit forecasts about their outcomes. Management actions and monitoring programs are carefully designed to generate reliable feedback and

> clarify the reasons underlying outcomes. Actions and objectives are then adjusted based on this feedback and improved understanding. In addition, decisions, actions and outcomes are carefully documented and communicated to others, so that knowledge gained through experience is passed on, rather than being lost when individuals move or leave the organisation.

Adaptive management has been successfully applied in numerous environmental planning contexts (Nyberg, 1999), and it offers particular promise for developing and implementing TMDLs.

Following the GAO report (USGAO, 2000) that found that significant data gaps hinder implementation of the TMDL program, Congress asked the National Research Council to examine in detail the "scientific basis" for the TMDL program (NRC, 2001), including:

- the information required to identify sources of pollutant loadings and their respective contributions to water quality impairment,
- the information required to allocate reductions in pollutant loadings among sources,
- whether such information is available for use by the states and whether such information, if available, is reliable, and
- if such information is not available or is not reliable, what methodologies should be used to obtain such information.

The National Research Council created the Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction to study these issues. Much of the committee's response revolves around utilization of adaptive approaches to the development and implementation of TMDLs. The committee describes adaptive implementation as an iterative application of the scientific method to decision-making whereby TMDL plans are "periodically assessed for their achievement of water quality standards including designated uses" (NRC, 2001).

The committee also devoted a great deal of attention to discussing "use attainability analysis," which examines the standard that water body is not complying with in relation to natural conditions, and "phased" or "iterative" approaches to TMDL development (NRC, 2001). It is important to clarify that, for TMDLs, adaptive management *per se* would be concerned with adjusting the amounts on the right side of the allocation equation

$$TMDL = \sum WLA + \sum LA + Background + MOS,$$

and not the TMDL itself. Adjusting the TMDL over time in response to better information or a use attainability analysis may provide a target load that is more likely to protect water quality, but it does not provide better information about sources of pollutants or whether the management strategy is improving ambient water quality. A phased approach to setting TMDLs also does not reveal gaps in the management strategy that are preventing compliance with the standard. The proper application of adaptive management to the above equation would produce terms that are more accurate and more feasible.

Adaptive management is a process of program design and implementation that is driven by the scientific method (NRC, 2001). Adaptive management has clear parallels with iterative model design, as described by Berthouex and Brown (1994):

> Knowledge is gained in small steps, each step guiding us to the next. We begin with a modest initial experiment which produces information we use to design the second experiment, which in turn guides the design of the third, and so on. Between each step there is a need for reflection, study, and creative thinking.

Hence, the initial margin of safety and TMDL implementation strategy can both be treated as hypotheses to be tested and refined as additional information becomes available and uncertainty is reduced. Additional information is gathered through monitoring and documenting 1) water quality parameters and 2) inspections and enforcement of the implementation strategy. A dynamic relationship between these two key components is the crux of adaptive management. The management strategy integrates the TMDL into practice, and water quality data show whether the TMDL is working. If these two activities are not coordinated, the management strategy is at best an educated guess.

Nutrient Impairment in the Upper New Hope Creek Arm of Jordan Lake

The Upper New Hope Creek Arm of Jordan Lake (Upper New Hope Arm) was listed as impaired on North Carolina's 303(d) list in 2002 for nonattainment of the state water quality standard for chlorophyll *a*. The Jordan Lake Stakeholders' Group was convened in 2003 to develop TMDLs for total nitrogen and total phosphorous in the Upper New Hope segment and to create a nutrient management strategy that will implement the TMDLs. Nonpoint sources are a significant portion of the load to the Upper New Hope Arm, and these sources will be responsible for attaining a corresponding share of nutrient reductions. Demonstrating that nonpoint sources are indeed responsible for a corresponding share of any reductions observed in total nutrient loads will be a substantial challenge.

The stakeholders have not yet targeted specific information-gathering and enforcement activities toward informing future iterations of the management strategy. Better information is needed on the quality and quantity of the NPS controls in order to properly evaluate the management strategy. Having better information on the management strategy and its local effectiveness becomes even more crucial if innovative strategies such as trading schemes or performance standards are included in the NPS management strategy to achieve load allocations.

Historical Nutrient Concerns in the B. Everett Jordan Reservoir

Jordan Lake was created for flood control, recreational, and water supply uses. It is headwaters of the Cape Fear River, which is formed just below the reservoir outfall at the Deep River confluence. The Jordan Lake watershed covers all or part of 10 counties and 25 municipalities and is almost 1,700 square miles in size (TJCOG, 2004). The process of planning the reservoir project was highly contentious due to landowner opposition and environmental concerns. Additional concerns were raised by researchers who questioned whether the beneficial uses of the reservoir could actually be attained, given the high probability of nutrient impairment (TJCOG, 1980).

Use attainability was a concern also because existing nutrient loads from point sources were to be higher than any other reservoir in the state (TJCOG, 1980). Wastewater dischargers were faced with much higher effluent standards when the lake became a water supply. Background sources would also contribute nutrients when the land was initially flooded, partly due to its fertile soils and partly due to the oxygen demanded by decomposing organic matter. Despite many concerns and objections, the US Army Corps of Engineers gradually moved ahead with construction of the reservoir until it was completed in 1981.

In addition to the watershed characteristics that make the lake prone to nutrient enrichment, it is also fairly shallow, with an average of 16 feet (TJCOG, 2004). A large amount of surface area relative to depth makes the lake highly susceptible to eutrophication, a process in which enclosed bodies of water accumulate algae. Excess algae can impair the ability of the lake to provide services such as aquatic habitat, recreation, and drinking water supply uses.

Jordan Lake eutrophication processes are "co-limited" because total algae levels are limited by either nitrogen or phosphorous, depending on the time of the year, algal species, and other conditions such as temperature and light. Northern areas of the lake tend to be more nitrogen limited with regard to algal growth. Water and nutrients in the Upper New Hope Arm have a much longer residence time (and therefore take longer to exhibit effects due to changes in loads).

Weiss et al. (1984) conducted an early water quality study on the new reservoir using data from December of 1981 to November of 1982 and found that, although nutrients were a factor in algae production, other factors such as light and temperature explained much of the variation in algae mass. Moreover, chlorophyll *a* levels did not always correlate with use impairments (Weiss et al., 1984). Indeed, Jordan Lake is currently meeting its designated uses. Nevertheless, chlorophyll *a* remains an important indicator of water quality and use suitability for various uses, and the state regulates its concentration in Jordan Lake at 40 µg/L. Exceedance of this standard in the Upper New Hope Arm precipitated the TMDL process for nitrogen and phosphorous.

Jordan Lake Stakeholder Project

The Jordan Lake Stakeholders project was created to inform development of "a Nutrient Management Strategy for the Jordan Lake Watershed that will be presented as a recommendation to the Environmental Management Commission" (TJCOG, 2004). The stakeholders are assisting the state with developing nutrient management strategies for all three Jordan Lake segments, even though the Lower New Hope Arm and the Haw River Arm are not listed on the state's 303(d) list. The nutrient management strategy is therefore also based on the state's classification of the entire water body as a nutrient-sensitive water.

The project is facilitated by the NC Division of Water Quality, the Piedmont Triad Council of Governments, and the Triangle J Council of Governments. In addition to project facilitators, the stakeholder group consists of representatives from each local government with land that drains to Jordan Lake, the Orange Water and Sewer Authority, various federal and state agencies (e.g., United States Fish and Wildlife Service, USEPA, the U.S. Army Corps of Engineers), and nongovernmental entities (e.g., nonprofits and business associations). The municipalities Apex and Cary also joined, as they withdraw water from the lake for municipal water supplies.

The Jordan Lake Stakeholders Group has met almost monthly since May of 2003 to discuss conditions, model results, and issues regarding implementation of a management strategy (TJCOG, 2004). Concerns have arisen during the planning process because of the inconclusive nature of some of the chlorophyll *a* data and modeling uncertainty, which do not clearly justify creating a severely restrictive nutrient management strategy (CH2MHILL, 2004).

Jordan Lake Water Quality

Jordan Lake has 38 tributaries listed as impaired on the NC 2004 303(d) list. Of those, approximately half are in the Upper New Hope Arm watershed. Despite the fact that most lake storage capacity is in the Upper New Hope Arm, inflow to the lake from this portion is dwarfed by that contributed by the Haw River. However, the lower Haw River portion of the lake generally does not mix with the Upper New Hope portion. The lower portion drains quickly to the dam outlet, and the middle segment of the lake prevents the Haw Arm from mixing with the Upper New Hope Arm (Tetra Tech, 2003). Therefore, only the watershed areas that drain to the Upper New Hope Arm will be considered in the Upper New Hope Arm nutrient management strategy.

Potential sources of impairment in the Upper New Hope Arm watersheds include (in no particular order) urban runoff/storm sewers, major municipal point sources, and non-urban development (NCDWQ, 2004). The heavily urbanized areas of the Upper New Hope Arm are fairly close to Jordan Lake. Point sources in the Upper New Hope Arm include three major wastewater treatment plants (Childress and Bathala, 1997).

Jordan Lake has been heavily monitored since it was impounded (Tetra Tech, 2001). Local governments, USGS, USACE, and NCDWQ have all performed monitoring in the lake in recent decades. USGS and NCDWQ perform the most spatially and temporally comprehensive monitoring.

Table 1. Summary of nutrient response-related water quality monitoring efforts in Jordan Lake, showing monitoring agency, parametric coverage, and approximate sampling frequency (Tetra Tech, 2001).

Agency	# lake sites	# near-lake sites	TP	PO_4	NH_3N	NO_x	TN	Chl. *a*	Algal Growth			DO	pH
									Type	Bio-mass	Bio-vol.		
DWQ	13	4	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
USGS/ TAWSMP	4	3	✓	✓	✓	✓	✓	✓					

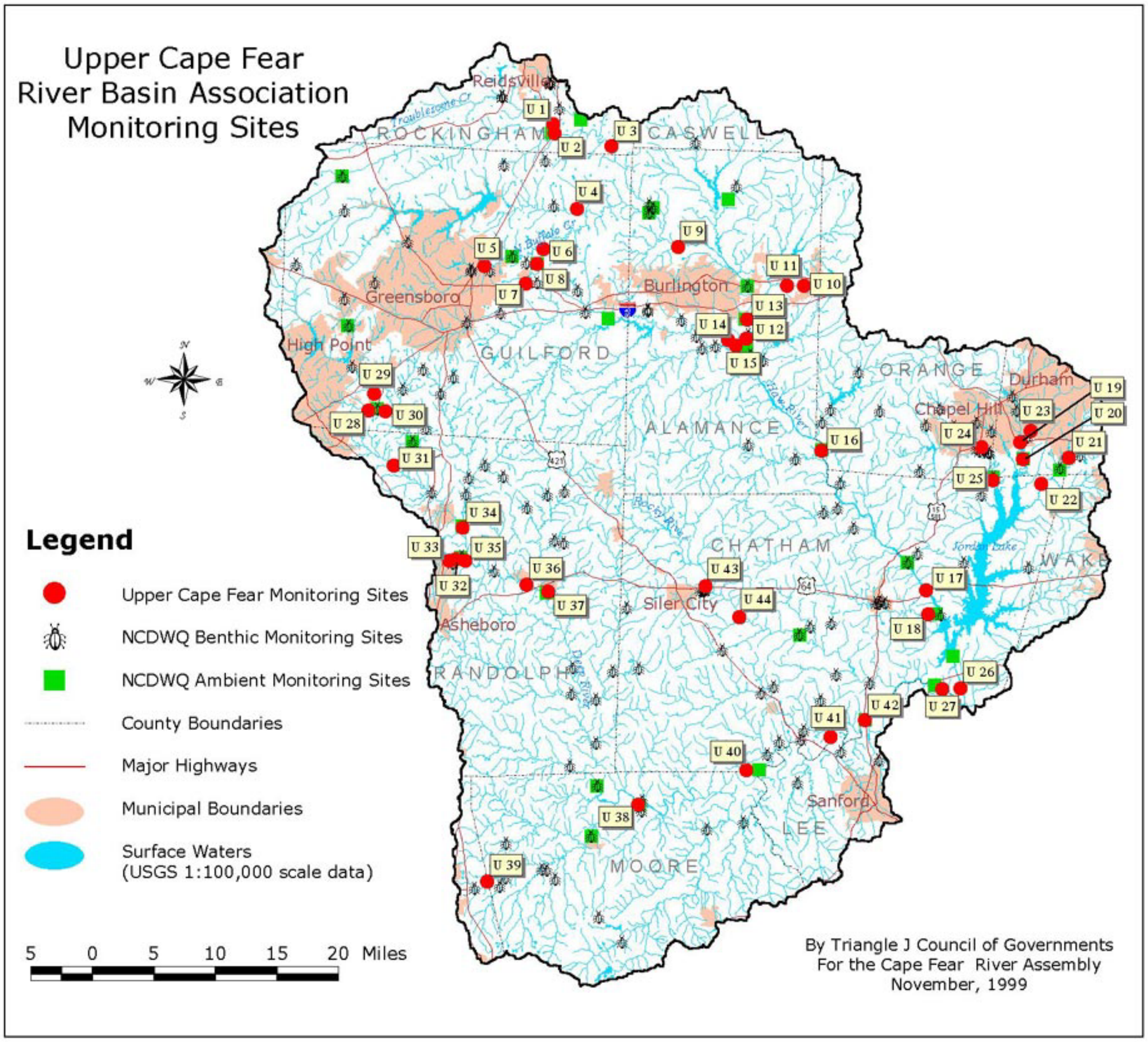
DO: dissolved oxygen
TAWSMP: Triangle Area Water Supply Monitoring Project
TP: total phosphorous
TN: total nitrogen

Numerous parameters have been monitored since the lake's impoundment; however, not all Jordan Lake tributaries have been monitored with any consistency. Most NC Division of Water Quality (NCDWQ) monitoring sites are located just downstream of wastewater outfalls (Childress and Bathala, 1997). United States Geological Survey (USGS) data collection sites are more oriented toward ambient monitoring, particularly of flow (Childress and Bathala, 1997).

The Triangle Area Water Supply Monitoring Project

The Triangle Area Water Supply Monitoring Project was begun in October of 1988 because of concerns about the impacts of growth on area drinking water supplies. It is a partnership of agencies that perform monitoring in the Triangle area, coordinated by the Triangle J Council of Governments. The project incorporates data from USGS and NCDWQ and has supplied a great deal of data for modeling efforts. Few sites were sampled by both, so incorporation of the two databases enhances areal coverage rather than temporal coverage of any one site. In addition to general monitoring for baseline trends, the project has had four phases with four distinct monitoring emphases, the most recent of which is nutrient concentrations. In Jordan Lake's watershed, approximately twenty sites have been monitored since 1999; about half of these were monitored for the entire period.

Figure 2. Existing water quality monitoring sites in the Upper Cape Fear River Basin (TJCOG, 2004). (The upper portion of the area shown drains to Jordan Lake.)



The Triangle Area Water Supply Monitoring Project analyzed total nitrogen and total phosphorous in both streams and lakes. Concentration of chlorophyll *a* is an indicator of algal mass in a water body that may be used as a surrogate for nutrient concentration. Chlorophyll *a* levels are monitored only in lakes (Childress and Bathala, 1997). Choosing depths at which to sample chlorophyll *a* can be problematic. According to Childress and Bathala (1997), "although algal biomass tends to decrease with increasing depth, …biomass at any single point in the water column can be highly variable."

For chlorophyll *a,* Childress and Bathala analyzed USGS high-performance liquid chromatography data rather than NCDWQ data analyzed with fluorometric methods. Unfortunately, USGS data may have been affected by a sample method collection change in April of 1992 (Childress and Bathala, 1997).[2] Still, a detectable and significant increase in chlorophyll *a* concentrations was apparent over the period 1988 to 1995. Childress and Bathala (1997) suggest that growing conditions or phosphorous stored in sediments may be partly responsible for the inverse relationship they observed between phosphorous and chlorophyll *a* concentrations.

Figure 3. Chlorophyll *a* trends in the Upper Cape Fear River Basin (Childress and Bathala, 1997).

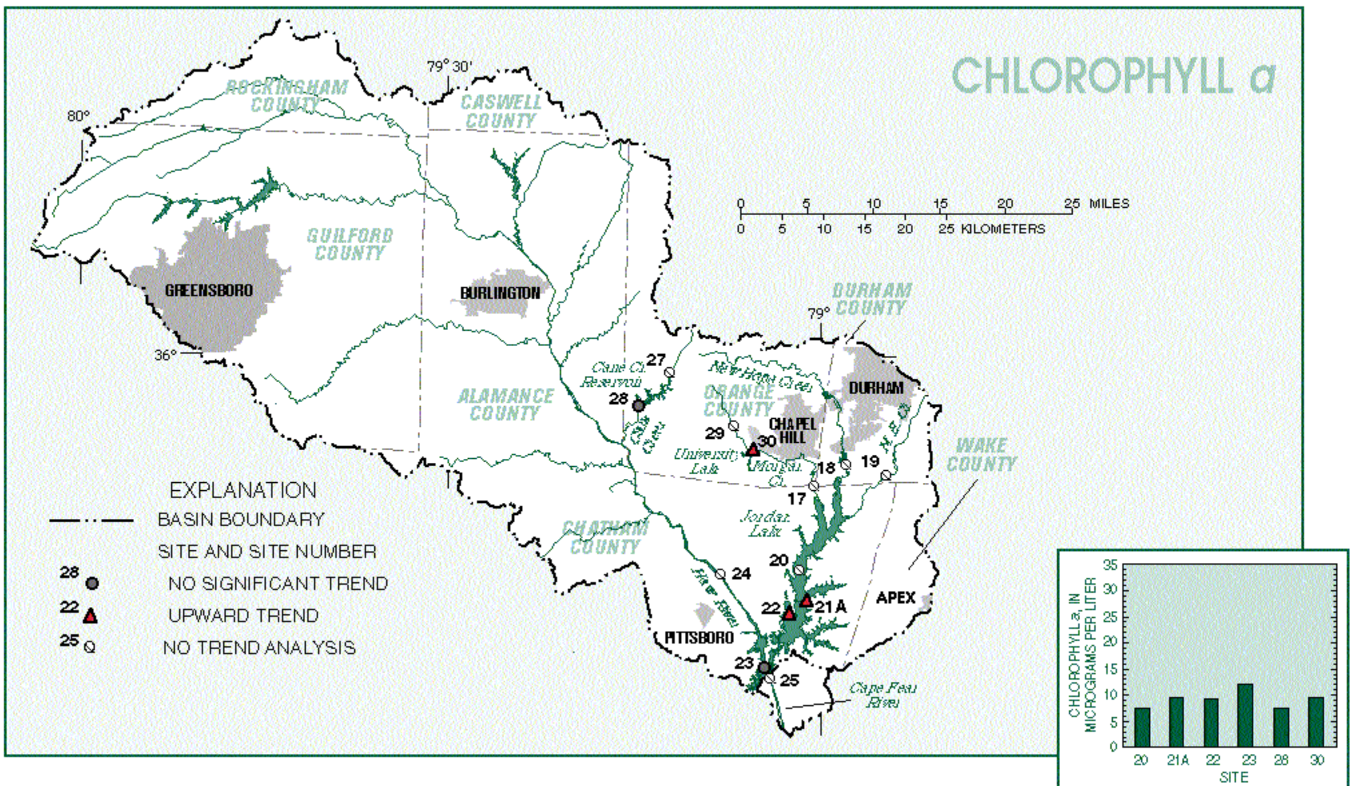


Figure 12.–Chlorophyll *a* trends in the upper Cape Fear River Basin, North Carolina.

The USGS analysis by Childress and Bathala (1997) on nutrient data indicated that

> The concentration of total nitrogen in lakes varied seasonally. Concentrations tended to peak in winter months and decline in summer months when lake productivity increases…. Most lake sites had no trends in total nitrogen concentrations during the 1983 through 1995 water years….

Phosphorous data for Jordan Lake did not exhibit a downward step-trend after a ban phosphate detergent was instituted, but stream monitoring sites did exhibit a general downward trend. Gradual decreases were observed at the one site in Jordan Lake that had phosphorous at observable detection limits (Childress and Bathala, 1997).

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[2] The Jordan Lake Nutrient Response Model analyzed data from both methods; USEPA has reportedly found "no significant trend [in relative standard deviation] by method across test species," although both methods are highly uncertain (Tetra Tech, 2004).

The Triangle Area Water Supply Monitoring Project performed trend analysis on total nitrogen (the sum of all nitrogen forms), nitrite plus nitrate, and organic nitrogen (Childress and Bathala, 1997). Nitrogen tends to peak during the non-growing season when algae uptake is lowest. Overall, nitrogen concentrations appear to decrease slightly over time at most sampling locations in the Upper Cape Fear, likely due to reductions in nitrogen in wastewater effluent (Childress and Bathala, 1997).

The Jordan Lake Water Quality Modeling Project

The Jordan Lake Water Quality Modeling Project was undertaken in 1999 by watershed jurisdictions (Burlington, Graham, Greensboro, Mebane, Pittsboro, and Reidsville) and the Orange Water and Sewer Authority. These partners were subsequently joined by Apex and Cary, municipalities which withdraw drinking water from Jordan Lake (TJCOG, 2004). The Jordan Lake Nutrient Response Model was undertaken to create a calibrated model for Jordan Lake wastewater dischargers that would enable location-specific standards as an alternative to state effluent limits issued under nutrient-sensitive waters designations. The model describe the system's responses to nutrient inputs and is used to set management targets. No state or federal funding was obtained for the effort; however, NCDWQ did provide some services and staff time for calibrating and verifying the models (TJCOG, 2004).

The model was based on USEPA's WASP5-EUTRO and was developed and calibrated using data from 1997 to 1999. NCDWQ performed extensive monitoring in 2000 and 2001 to fill in gaps. However, during this same time period a severe drought occurred, so these data may not be representative of general conditions. Validation with 2001 data demonstrated a need to perform a constrained recalibration of the entire model (NCDWQ, 2003). The recalibration produced in a slight reduction in model fit. Data from 2000 were too sparse to be used in calibrating the model, so they were added to the 2001 data for model validation after recalibration. This model was run on approximately 30 lake segments in 45-minute time steps to assess the effects of applicable parameters on algae content. Algae species were modeled as a group because differentiation between species for model predictions is not currently feasible (NCDWQ, 2003).

The state standard does not specify an allowable exceedance frequency for chlorophyll *a* standard, so the Jordan Lake Water Quality Modeling Project obtained approval from the USEPA to use a 10% exceedance frequency (NCDWQ, 2004c). In the Upper New Hope Arm, concentrations have often exceeded this standard. The model tends to slightly underestimate excursions, particularly in the fall when data are less complete, based on comparisons with NCDWQ observed excursions (Tetra Tech, 2004).

Jordan Lake TMDL Watershed Model Development

Previous modeling efforts did not enable assessments of nonpoint sources, so the Jordan Lake Stakeholders Group undertook an enhancement of the Jordan Lake Nutrient Response Model. A generalized watershed loading function (GWLF) model was developed to estimate NPS loads. The complexity of the GWLF "falls between that of detailed simulation models and simple export coefficient models" (NCDWQ, 2003). Current tax parcel information was combined with land cover data from the 1992

National Land Cover Database to characterize land uses by subwatershed. The GWLF also incorporated parameters for "1) soil and hydrologic properties, 2) nutrient concentration, buildup, and runoff assumptions, 3) onsite wastewater disposal information, and 4) meteorological data" (NCDWQ, 2003). Jordan Lake's 58 hydrologic units were categorized into "hydrologic response zones" based on similar characteristics. A 10-year time series was used to estimate loads by zone. The GWLF showed that the highest field-scale loading rates come from medium-density unsewered residential and barren land (NCDWQ, 2003). The GWLF was linked with a spreadsheet that assisted with quantifying the stream transport component of nutrient delivery to the lake based on land use and hydrology (TJCOG, 2004).

Table 2. Seasonal distribution of total delivered nitrogen loads by source area (lbs) (modified from Appendix B in Tetra Tech, 2003).

Source area	Jan-Feb-Mar	Apr-May-Jun	Jul-Aug-Sep	Oct-Nov-Dec	Annual total
Haw River NPS	1,110,429	521,678	465,069	328,336	2,425,511
Haw River PS	391,561	313,790	238,006	216,232	1,159,589
Upper New Hope NPS	247,355	107,794	112,939	100,911	568,998
Morgan	45,879	20,563	15,401	15,949	97,792
New Hope	96,905	42,493	45,859	40,946	226,204
Northeast	68,581	28,791	36,390	29,010	162,771
Little/Bolin	35,990	15,947	15,289	15,006	82,232
Upper New Hope PS	147,725	116,226	92,022	103,337	459310
Lower New Hope NPS	188,241	78,145	72,984	60,289	399,659

PS: Point source
Notes: Nonpoint loads are based on the average of the 10-year model simulation run (April 1991-March 2001 meteorology), while point source loads are based on the average of the 1996-1998 analysis of delivered loads provided by Research Triangle Institute.

Table 3. Seasonal distribution of total delivered phosphorous loads by source area (lbs) (modified from Appendix B in Tetra Tech, 2003).

Source area	Jan-Feb-Mar	Apr-May-Jun	Jul-Aug-Sep	Oct-Nov-Dec	Annual total
Haw River NPS	265,386	60,261	160,325	60,808	546,780
Haw River PS	34,773	29,316	25,017	22,970	112,076
Upper New Hope NPS	42,370	13,252	24,641	15,555	95,818
Morgan	5,135	1,228	2,910	1,513	10,785
New Hope	18,860	5,779	11,010	6,822	42,472
Northeast	12,084	4,257	7,289	4,925	28,554
Little/Bolin	6,291	1,988	3,433	2,296	14,007
Upper New Hope PS	7,564	4,453	3,257	5,832	21,106
Lower New Hope NPS	35,639	8,668	21,506	9,809	75,623

Notes: Nonpoint loads are based on the average of the 10-year model simulation run (April 1991-March 2001 meteorology), while point source loads are based on the average of the 1996-1998 analysis of delivered loads provided by Research Triangle Institute.

Tetra Tech claims that the watershed model "provides a sound technical basis for apportioning the gross allotment of a total nonpoint source load allocation back to individual source areas and land use types" (Tetra Tech, 2003). The model simulation shows that, in the Upper New Hope Arm, the source areas supplying the most nutrients from nonpoint sources are New Hope and Northeast.

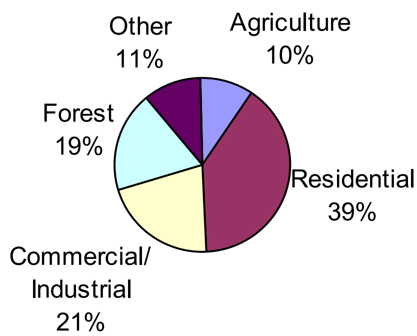

Figure 6. Nonpoint sources of nitrogen in the Upper New Hope Arm, as a percentage of total NPS contribution.

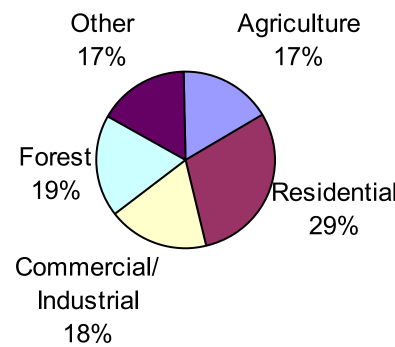

Figure 7. Nonpoint sources of phosphorous in the Upper New Hope Arm, as a percentage of total NPS contribution.

The Jordan Lake Nutrient Response Enhancement showed that nonpoint sources taken as a whole are responsible for the larger fraction of the total load in the Upper New Hope Arm. Of nonpoint sources in the Upper New Hope Arm, most categories of land use were fairly evenly responsible for the total load (Tetra Tech, 2003). Developed uses account for about a third of acreage in the watershed. This portion is expected to increase in coming decades as land is converted from agricultural and forest uses to urban development (Tetra Tech, 2003).

The models and supporting materials were submitted to the state in April of 2002. For a detailed discussion of the models and their calibration and validation, see NCDWQ's Summary of Jordan Lake Nutrient Response Model Enhancement and Watershed Model Development memorandum dated December 10, 2003 (NCDWQ, 2003) and the Tetra Tech B. Everett Jordan Lake TMDL Watershed Model Development report (Tetra Tech, 2003).

The Upper New Hope Arm Nutrient TMDLs

The TMDLs proposed for nitrogen and phosphorous are based on a goal of no more than 10% of days in an extended growing season[3] exceed chlorophyll *a* value of 40 µg/L (TJCOG, 2004). NCDWQ determined the overall nutrient reduction targets necessary to achieve this standard (NCDWQ, 2003).

Preliminary Reduction Targets

The preliminary nutrient reductions proposed by DWQ were different for the three sections of the lake. Target reductions and caps were calculated based on loads averaged annually from samples taken between 1997 to 2001 (TJCOG, 2004).

Table 6. Preliminary reduction targets of each lake segment (TJCOG, 2004).

Lake segment	Total nitrogen target	Total phosphorous target
Upper New Hope Creek Arm	35% reduction	5% reduction
Haw River Arm	5% reduction	20% reduction
Middle Portion	Cap at 1997–2001 levels	Cap at 1997–2001 levels

Separate strategies are being developed for the watersheds of all three segments due to their differing characteristics and lake hydraulics. There is little mixing among segments, and most of the water stored in each segment comes from the watershed that drains to the segment (Tetra Tech, 2003; Miller, 2004). Therefore, loads from the Haw River Arm and middle segment do not need to be considered in the Upper New Hope Arm NPS nutrient management strategy.

These targets formed a preliminary hypothesis on which to study alternative management strategies while better information was being analyzed from the completed Jordan Lake Nutrient Modeling Project. In May, 2004, these target percentage reductions were to be applied to both point and nonpoint sources (TJCOG, 2004). The strategy was later amended to better reconcile some priority concerns that conflicted. In particular, the nutrient targets were changed from percentage reductions to a concentration limit for effluent dischargers and a limit on pounds per acre per year exported from land uses. This approach was deemed more fair to those actors who already had implemented abatement controls and best practices (Miller, 2004).

Proposed NPS Nutrient Management Strategy

As of this writing, NCDWQ is creating the official Upper New Hope Arm NPS nutrient management strategy. This strategy will be based on the draft Upper New Hope Arm NPS Nutrient Management Strategy created by the Jordan Lake Stakeholders (the

[3] An extended growing season average rather than an annual maximim was decided upon to account for critical seasonal concentrations (USEPA, 2003).

October 2004 draft is included as Appendix A). The draft strategy resembles the Neuse Nutrient Sensitive Water Rules adopted by the NC Environmental Management Commission in December of 1997 to reduce nutrient loads to the Neuse estuary.

The strategy drafted by the stakeholders is broken up into "Management Modules," which roughly correlate with control measures by NPS load source. The draft management strategy involves preservation of riparian buffers, agricultural nitrogen reductions, stormwater management for new and existing development, onsite wastewater standards, and forestry management. The last module proposes a trading mechanism for point and nonpoint sources of nutrients. NPS nutrient load limits that are proposed for land uses in the Upper New Hope Arm are 4.1 lb/acre/year of nitrogen and 1.1 lb/acre/year of phosphorous (TJCOG, 2004).

An Adaptive Approach to Implementing NPS Nutrient TMDLs

The natural starting point to an adaptive TMDL implementation strategy is to identify and quantify sources of uncertainty so that the management strategy can include measures to reduce them. For each water quality model and each management module used in the Upper New Hope Arm nutrient management and TMDL implementation strategies, areas of uncertainty and methods to address each need to be identified. Conveniently, the same indicators and information that enable reduction of modeling uncertainty also allow the effectiveness of each module to be evaluated in light of the overall goal of reducing NPS nutrient loads. A critical evaluation of control efficiencies and water quality responses is the foundation of an adaptive management approach.

A significant (and often unspoken) source of uncertainty in many management strategies is whether the controls will be implemented as intended. If an adaptive approach were taken to program design, such uncertainties would be explicitly stated at the outset. The program would be designed to gather information *about* implementation *through* documenting the actions taken. For example, the efficacy of enhancing inspections of stormwater controls to reduce runoff would be evaluated by examining inspections documentation. Clearly, the information gathered from performance and compliance monitoring programs must also be well managed and documented.

The NRC Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction, in its analysis of adaptive management and TMDLs, proposed that management actions with a high degree of certainty be undertaken first (NRC, 2001). In the Upper New Hope Arm, the state has already placed additional discharge limits on point sources under NC nutrient-sensitive water rules.[4] An important next step in the nutrient management strategy would be to identify which controls are the most likely to be effective and cost-effective for nonpoint sources, so that nonpoint

[4] Nevertheless, point sources in the Upper New Hope Arm may be capped at current levels once the TMDL implementation strategy is adopted (TJCOG, 2004).

sources can be made responsible for their fair share of nutrient reductions. In general, the USEPA (2001) has noted that "prevention of degradation… is more cost-effective and more likely to succeed than watershed restoration."

In July of 2004, the consultant CH2MHILL (2004) recommended that "due to the questions concerning the interpretation of the chlorophyll *a* standard for Jordan Lake, issues related to the quality of the chlorophyll *a* data, questions surrounding the effects of changed nutrient ratios on algal species composition, and the model error and uncertainty," adaptive management should be applied to the TMDL development and nutrient management strategies. CH2MHILL (2004) recommended that the Jordan Lake Stakeholders pursue an adaptive management approach, described in the following "steps":

1. Implement point and nonpoint nutrient management programs that will effectively cap nutrient loads at their current levels (1997 through 2001 average annual loads).
2. Develop a monitoring strategy that can be used to evaluate the chlorophyll *a* standard and revise the model.
3. Implement the monitoring strategy.
4. Review the monitoring results and revise the chlorophyll *a* standard and model as appropriate.
5. Develop Phase 2 of the TMDL and NMS [nutrient management strategy].

This series of "steps" will do little to further the utilization of an adaptive approach because studying the relationship between water quality and the management strategy is not a step in the process.

An alternative series of steps to implementing an adaptive nutrient management strategy might be:

1) identify areas of uncertainty
- in the watershed assessments
- in the water quality models

2) design a nutrient management strategy
- to gather information about implementation and effectiveness of controls, reducing uncertainty in watershed assessments
- to reduce nutrient loads

3) design pilot projects
- to gather in-depth, local information on efficacies of different controls
- to test promising but uncertain control measures
- to assess relationships between controls and water quality responses
- to define the quality and quantity of information needed to evaluate the strategy

4) design a water quality monitoring strategy
- to gather information about baseline and trend water quality conditions to reduce uncertainty in models
- to study responses in waters receiving experimental treatment from pilot projects

- to document changes (positive or negative) in receiving waters due to implementation of the management strategy

5) evaluate the nutrient management strategy in light of its effectiveness
6) see step 1 (process begins again)

In the sections that follow, some considerations for designing an adaptive TMDL implementation strategy for nonpoint sources of nutrients in the Upper New Hope Arm are discussed. The proliferation of reports on techniques for watershed management indicates that thinking up ways to protect watersheds is not difficult. Similarly, technological methods of assessment are more advanced than the ability to effectively use and manage this information. In the management of water quality, what are lacking are effectively implemented strategies and data linking these strategies to water quality conditions.

Uncertainty and the Jordan Lake Water Quality Models

The Jordan Lake Stakeholders Group has yet to summarize the uncertainties in the various water quality and watershed models it used and to propose a comprehensive review of how those uncertainties can be reduced. Tetra Tech, in its 2003 report "B. Everett Jordan Lake TMDL Watershed Model Development," gave an uncertainty analysis that is included here as Appendix B. Tetra Tech characterizes limitations in the data as producing the significant uncertainty observed in the models.

The Jordan Lake Nutrient Response Model has significant uncertainty in particular chlorophyll *a* values as measured by differences between paired observations and model predictions (CH2MHILL, 2004; Tetra Tech, 2004). However, Tetra Tech has stated in a technical memorandum (2004) that such uncertainty is due to many factors besides model imprecision. Tetra Tech (2004) argued that the relationship between values at different points in time and space is more important than the relationship "between individual points at individual stations." Tetra Tech defended its model calibration strategy with the claim that it was simultaneously adjusted to achieve accuracy for central tendencies of multiple parameters at different stations, not to achieve close predictions of individual data points (Tetra Tech, 2004).

Tetra Tech (2004) summarizes the relationship of the Jordan Lake model and uncertainty for management purposes:

> In sum, the Jordan Lake model as currently implemented is not a particularly good predictor of individual point measurements of chlorophyll *a* – and cannot be without much better knowledge of external forcing functions. The dynamic, riverine nature of the influent segments of the lake likely means that significant natural variability would still be present even if these forcing functions were known precisely. But, this is not the appropriate test of the model. Instead, the model should be judged on its ability to replicate longer-term spatial and temporal trends and the frequency distribution of chlorophyll *a* concentrations greater than the criterion. For these purposes the model appears to perform well. The significant uncertainty that is present does provide a compelling rationale for use of adaptive management to achieve goals – but is not an excuse for inaction.

Tetra Tech claims that the model's ability to predict frequency of values around the criterion of 40 µg/L is sufficient to enable the creation of a TMDL. For most of the year, plots of model predictions are fairly close to observations, with a major exception of late fall predictions (Tetra Tech, 2004). There is very high variation in data points without the models, that is, plus or minus two standard deviations (Oblinger, 2004). All three tests used to determine chlorophyll *a* concentrations (spectophotometry, high-performance liquid chromotography, and fluorometry) also exhibit high variation in values from particular samples (Tetra Tech, 2004). Algal concentrations in samples may also vary greatly due to the grab sampling method, sparse tributary data, and the degree of light penetration in the water column (Tetra Tech, 2004).

Several potential sources of uncertainty have not been mentioned in the documentation of the models or the planning process. For other parameters of concern, most importantly nitrogen and phosphorous, the current tributary monitoring network does not have sensitive enough equipment to detect ambient levels because it was designed to monitor effluent loads, which have much higher limits of detection (Miller, 2004). Also not discussed is whether reduced sediment loads will affect algal levels in Jordan Lake. This issue merits further study, as many of the management modules that involve stormwater retention could reduce total suspended solids and therefore increase photosynthesis in the lake.

Designing and Implementing Effective Nutrient Control Programs

According to the Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction, "the most frequently cited criticism of TMDL programs across the country is the failure of states to implement pollution control measures following calculations of waste load and load allocations" (NRC, 2001). This translates into uncertainty with regard to the management strategy: there is no guarantee that it will be implemented as designed. The TMDL management strategy components most likely will be intended to be applied evenly and in concert with one another; piecemeal implementation is more likely to have unintended consequences. For example, some jurisdictions might adopt strict regulations on new development. If other watershed jurisdictions do not improve their codes to a comparable level, new development may locate in the less-regulated area (and would have greater impacts, all else being equal).

Upper New Hope Arm governments already have various development management and environmental regulations, but these vary in stringency by jurisdiction. Several jurisdictions with land in both the Upper New Hope watershed and the Neuse River Basin adopted Neuse buffer and stormwater rules in both watersheds. These jurisdictions recognized the additional protection that the Neuse rules offered, and perhaps they anticipated that a nutrient management strategy for the Upper New Hope Creek watershed was not far behind. Therefore, there is significant variation in the degree to which jurisdictions are already implementing components of the draft NPS nutrient management strategy. However, current target Upper New Hope nutrient limits are even lower than Neuse limits, so even jurisdictions that got ahead of the curve by adopting the Neuse rules will still have to make adjustments to their local regulations.

One of the primary ways that local governments reduce impacts of land use activities on water quality is to incorporate best management practices[5] (BMPs) into their local codes and ordinances. BMPs can be used for many different land uses and activities, such as forestry, agriculture, commerce, and residential development, and are more commonly required if the activity is an intense or high-impact use. For example, in NC water supply watershed protected areas, residential developments with densities over 24% must have an approved stormwater management system of BMPs. They can be engineered structures, such as retention ponds, or nonstructural measures, such as areas where disturbance is limited.

BMPs can be used to reduce the impacts of parcel-level activities on larger environmental systems, preventing other, costlier problems. Numerous watershed, development management, and site plans call for jurisdictions to implement BMPs and other practices to lower the impacts of development, but systems to track BMP performance are often an afterthought to figuring out which BMPs should be used in what situation. Currently, there is a great deal that is usually not known about on-the-ground BMPs:

- where they are
- how many there are
- whether they were properly installed
- how effective they are
- how well they are maintained
- how much pollution they remove

This lack of information translates into uncertainty in watershed assessments and uncertainty regarding the effectiveness of management measures. BMPs may introduce uncertainty in the assessments of watersheds as they modify the effects of development and other land use activities, altering the accuracy of simple export coefficients for different land uses. BMPs are also a potential source of uncertainty in management strategies because the efficiencies at which they are assumed to remove pollutants may be not be based on local conditions, actual maintenance schedules, and numerous other variables. Information on implementation and performance of BMPs over time is necessary for evaluating their aggregate effects on water quality.

Stormwater BMPs may be structural or nonstructural. Structural BMPs are designed to convey or treat a particular amount of stormwater in a particular amount of time. They are required in many kinds of high- and medium-density developments to mitigate runoff volumes and rates. Designing systems to treat urban runoff for water quality is quite challenging because of the large variations in flows associated with storms. Generally, structural measures that reduce rates of runoff will also provide some benefit on nutrient reduction through retention.

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[5] Although the term "BMP" is also used in the literature to refer to a broad spectrum of practices that can include education, outreach, planning, and pollution reduction measures, I use the term more narrowly to refer to physical land-based practices that are designed, can be inspected, and can be shown on maps and site plans.

Stormwater BMPs are usually required to be shown on site plans, may require a post-construction as-built certification, and are typically inspected at some point during or after construction. Some jurisdictions, particularly those who have incorporated the Neuse stormwater rule into their local codes, inspect stormwater BMPs annually. These inspections are usually done by local sedimentation and erosion control divisions or stormwater divisions, if they exist. Smaller municipalities often rely on their county to perform inspections on construction sites, but there are some counties without these programs where the state must oversee activities related to construction and development.

Nonstructural measures include grassed or vegetated swales, riparian buffers, and placing sensitive or critical areas off-limits to disturbance. Such areas function to diffuse flows and take up nutrients. These BMPs are more difficult to evaluate for effectiveness, but they may be visually inspected. Vegetative BMPs are usually cheaper to maintain than structural measures, but they may be more land intensive. Nonstructural/vegetative measures that make land off-limits for development are used more often in rural situations. A great deal of research is available on the effectiveness of riparian buffers for nutrient removal generally (Correll, no date). Information on removal efficiencies and maintenance requirements specific to the Upper New Hope Arm is needed. Inspections during land transfers and development processes, and periodically thereafter, are needed to ensure that riparian buffers are being preserved. Any harvesting permitted in the buffer should be inspected more frequently than non-buffer harvesting operations. If violations are not restored immediately, they should be tracked for future restoration projects.

Agricultural BMPs are planned, implemented, and installed by county Soil and Water Conservation Districts, with funding from the Agriculture Cost-Share Program and some assistance from county Cooperative Extension offices (Christensen and Loser, no date). Farmers contribute 25% of the BMP project cost, either directly or through in-kind contributions. The Agriculture Cost-Share Program divides agricultural BMPs into four purposes:

1) Sediment/nutrient delivery reduction from fields
2) Erosion reduction/nutrient loss reduction in fields
3) Proper animal waste management
4) Protecting streams from animals

Completed agricultural cost-share BMPs are subject to random checks by the Division staff and District personnel, and there are additional requirements if the BMP is for animal waste. Farmers who fail to maintain their BMPs properly may have to repay some or all of the original cost share funds (NCDWQ, 2004d). Properly installed and maintained BMPs for any of these purposes could have some positive effects on nutrient reduction.

There are a number of challenges to accomplishing the dual objectives of maintaining (and, when possible, improving) both farm profitability and environmental quality when implementing agricultural conservation measures (modified from Christensen and Loser (no date) of the NRCS):

- Linking the conservation practice/BMP to measured improvements in water quality and other natural resource conditions.
- Designing conservation practices and BMPs that adequately account for social considerations, such as the characteristics and needs of farmers with limited capital resources.
- Ensuring that the costs of conservation practices and BMPs are commensurate with the time needed to recoup initial investments, learning costs, and depreciation of the equipment.
- Reducing conservation practice and BMP implementation requirements so they are not too labor-intensive and/or technically demanding relative to the capabilities of the producer.
- Increasing the availability and accessibility of education, technical, and financial assistance resources for farmers and ranchers to effectively facilitate their adoption of conservation practices and BMPs.
- Recognizing that producers cannot simply pass on increased production costs to consumers.

According to Christensen and Loser (no date), the Natural Resources Conservation Service (NRCS) state conservationist "determines which of the national practices are appropriate for use in the state and adapts them to local conditions. Conservation practice standards and their specifications are revised at least once every five years to ensure that NRCS is using the latest proven science and technologies available." According to NCDWQ (2004a), "written strategy plans are used to prioritize the BMPs in terms of effectiveness for water quality protection." However, in practice, management plans have generally not adequately documented how BMPs achieve reductions, especially on county or watershed scale.

Any local program to manage nutrients under a TMDL should have a high rate of compliance and good information about compliance. Burby and May (1996) conducted a study of enforcement and compliance with local development regulations. They found that certain program components were associated with higher rates of compliance:

Steps producing a 10% to 20% improvement in compliance
- improve adequacy of staffing
- increase effort devoted to on-site inspections

Steps producing a 5% to 10% improvement in compliance
- institute state requirement of local code enforcement
- increase technical assistance

Regarding the top factors, Burby and May explain that "enforcement results in North Carolina could be enhanced significantly if local governments allocated more resources for the code enforcement function, particularly for additional staff, staff training, and legal support."

Other factors that may be associated with higher rates of compliance include improving staff technical expertise, developing proactive enforcement goals, employing flexible enforcement strategies, and improving the level of legal support of code enforcement (Burby and May, 1996). Burby and May (1996) note that highly coercive systems of enforcement have sometimes been associated with a negative influence on compliance, suggesting that enforcement should be balanced with cooperative approaches and building good working relationships with the regulated community. Burby and May caution, however, that overly flexible compliance, especially if coupled with an under-resourced inspections and enforcement department, may result in "lax enforcement and a weak level of commitment to comply" among the regulated community.

Joseph Skupien of the New Jersey Somerset County Engineering Department has provided the USEPA with an excellent analysis of the complexities of long-term implementation of structural stormwater BMPs. Skupien (1995) states that

> failure to meet inspection and maintenance BMP responsibilities not only leads to diminished BMP performance but may also create new health and safety threats that exceed those the BMPs were designed to prevent…. [Such] a result represents both a failure to realize a gain on the resources already invested in BMPs and the cause of significant additional expenditures.

The author emphasizes the importance of a well-integrated program of inspections, maintenance, and performance monitoring before, during, and after construction to achieve good returns on BMP investments. Skupien (1995) provides a basic outline that local governments could adapt to fit local circumstances:

- official inclusion of inspection and maintenance in overall stormwater management program
- sufficient and stable funding
- adequate equipment and materials
- trained and motivated staff
- regular performance of routine maintenance tasks
- timely performance of emergency maintenance tasks
- regular, competent inspections
- performance guarantees and defaults
- accurate recordkeeping
- productive self-evaluation and interaction

These criteria could be incorporated into programs for agricultural BMP and on-site wastewater performance monitoring as well.

A specific example of a program undertaken to both reduce uncertainty and ensure program implementation for the onsite wastewater module could examine rates of septic tank failure in the watershed. If such a study is not feasible, the recently completed Wake County onsite wastewater study may provide some parameters could be adjusted for other situations. Better information on septic system failures would enable creation of a targeted policy and give better numbers for use in implementation spreadsheets and future models. For example, Orange County recently obtained new database software for tracking septic system inspections. Formerly, a simple Microsoft Excel spreadsheet was used to track systems, which was periodically queried to determine inspections needs. (Orange County's Department of Environmental Health also has a policy of performing inspections on existing systems before inspecting and issuing permits for new systems.) All county environmental health agencies should consider obtaining a database system that helps track systems of concern and inspections results, schedules, and workloads. Additional education and certifications for system operators should also be considered.

Enforcement programs must be enhanced to ensure that existing state, regional, and local regulations are implemented as intended and to document maintenance and enforcement of additional NPS controls. Such documentation will be needed whenever it is necessary to assess the strategy, its effectiveness, or the need for its revision. Knowledge gained from a system of tracking and analyzing the results of inspections and enforcement can be evaluated to adjust programs. The USEPA (no date) suggests some criteria that can be used to determine the extent to which management measures are implemented and maintained:

- Determine the extent to which management measures and practices are implemented in accordance with relevant standards and specifications.
- Determine whether there has been a change in the extent to which management measures and practices are being implemented.
- Establish a baseline from which decisions can be made regarding the need for additional incentives for implementation of management measures,
- Measure the extent of voluntary implementation efforts,
- Support work-load and costing analyses for assistance or regulatory programs,
- Determine the relative adoption rates of various management measures across different geographic areas,
- Determine the extent to which management measures are properly maintained and operated.

It is important to emphasize that evaluations of program effectiveness based on administrative measures must not take priority over evaluations of program effectiveness based on longitudinal data receiving water quality. If only administrative outcomes are examined, the strategy is not utilizing adaptive management.

A local program that was designed using these common-sense principles would be better equipped to ensure that the NPS strategy it claimed to execute was actually performing as promised. The jurisdictions with area that drains to Jordan Lake already have a number of programs and resources with which to manage NPS pollution. Better information about on-the-ground, in-the-field practices would enable more accurate estimates of nonpoint loads, which, combined with better monitoring data, will reduce overall model uncertainty. The Jordan Lake Stakeholders Group should begin discussing how jurisdictions will implement the Upper New Hope nutrient management strategy and how such programs can be designed to facilitate enforcement and assessment of BMP implementation.

Water Quality Monitoring

Water quality monitoring is a crucial part of adaptive management. Monitoring water quality can help reduce the uncertainty in estimating NPS contributions because it helps establish a relationship of “physical, chemical, and biological characteristics of receiving waters to land use characteristics” (USEPA, no date). The Committee on Opportunities in the Hydrological Sciences (quoted in Jain and Singh, 2003) has stated

> "Modeling and data collection are not independent processes. Ideally, each drives and directs the other. Better models illuminate the type and quantity of data that are required to test the hypotheses. Better data, in turn, permit the development of better and more complete models and new hypotheses."

Such a cyclical approach is the essence of adaptive management. However, creating, calibrating, and verifying improved models is just one application of water quality monitoring. In an adaptive management framework, longitudinal water data also document the effectiveness of the management strategy, demonstrate compliance with standards, and influence the form of the management strategy itself.

Designing a monitoring strategy begins with an assessment of existing data and an identification of the objectives of the monitoring program. Objectives drive the choice of temporal, spatial, and analytical requirements that determine the type of monitoring framework needed, including considerations such as watershed "scale, variable selection, methods, and sample size" (USEPA, no date). According to Mary Giorgino of the USGS (2004), the question of "What data are needed to inform decisions?" must be answered before the question of how those data are to be obtained.

Ms. Giorgino believes that the Jordan Lake Stakeholders Group has a fairly good idea of what its monitoring objectives should be (Giorgino, 2004). However, the goals and objectives have not been fleshed out into a draft monitoring strategy. Ms. Giorgino (2004) has stated that specific components of the monitoring strategy will probably include

- Stakeholder commitment to long-term process
- Sampling appropriate water-quality variables at many locations in the lake (and at multiple depths at each site)
- Tracking lake levels, inflows, and outflow
- Sampling water quality and recording streamflow at significant tributaries
- Sampling across the range of hydrologic and climatic variation
- Quality-assuring the hydrologic and water-quality data
- Tracking multiple measures related to "land-use change" over time
- Documenting land-management policies and implementation actions in the watershed related to nutrients and sediment
- Documenting water-quality management changes related to nutrients, such as altered wastewater permits, etc.
- Planning at the outset for data verification, storage, retrieval, and distribution mechanisms
- Scheduling milestones for information reports and feedback

One possible goal of the monitoring strategy is to enable model recalibration and confirmation of nutrient concentration targets (Miller, 2004). Another is to "track trends in nutrient loads in conjunction with nutrient-management activities" (Giorgino, 2004). The monitoring strategy is to be one of the first initiatives in the nutrient management strategy, implemented within one year of TMDL approval. The stakeholders will begin drafting a water quality monitoring strategy in 2005 (Miller, 2004). The processes of deciding which goals and objectives are to guide the monitoring effort and deciding which specific parameters the program will monitor should both be documented.

It is not yet clear who will administer the monitoring activities for the Jordan Lake NPS nutrient management strategy. Currently, the coalition of wastewater dischargers in the Upper Cape Fear, the Upper Cape Fear River Basin Association, conducts monitoring and modeling for compliance purposes. Jordan Lake monitoring activities may be a subset of the Upper Cape Fear River Basin Association of local governments with land area in Jordan Lake, or a similar management organization may be created (Miller, 2004).

Numerous frameworks and guidance documents are available on the proper design and specifications of monitoring networks for different needs (USGS, no date; Ward, 1986). USEPA has a guidance manual specifically targeted toward monitoring nonpoint sources (EPA, 1997a). There is usually a tradeoff to be made between analytical comprehensiveness and cost feasibility. Monitoring can be an expensive process, and sufficient resources must be mobilized to ensure that the data are of high quality. For maximum effectiveness, the monitoring strategy must be targeted and designed to achieve specific purposes. The table below lists the main purposes for which monitoring might be undertaken and the usual differences between them. Purposes and specific program design will naturally need to be tailored to the local situation.

Table 8. General characteristics of different types of monitoring networks (USEPA, no date).

Type of Monitoring	Number and Type of Water Quality Parameters	Frequency of Measurements	Duration of Monitoring	Intensity of Data Analysis
Trend	Usually water column	Low	Long	Low to moderate
Baseline	Variable	Low	Short to medium	Low to moderate
Implementation	None	Variable	Duration of project	Low
Effectiveness	Near activity	Medium to high	Usually short to medium	Medium
Project	Variable	Medium to high	Greater than project duration	Medium
Validation	Few	High	Usually medium to long	High
Compliance	Few	Variable	Dependent on project	Moderate to high

In the case of the Upper New Hope Arm TMDLs, monitoring activities have been ongoing and varied. Methodological consistency is lacking in data on long-term trends. It is important that the monitoring network is designed thoughtfully in anticipation of future needs, to reduce shifts in sample collection method. Most water quality monitoring programs already have documentation and quality assurance protocols, but improvements in information coordination and dissemination could be improved to facilitate utilization of adaptive management approaches.

High-quality data on flow are needed to estimate pollutant concentrations and to model hydrology. Most flow data are collected at monthly intervals, and USGS claims that this interval adequately captures flow variations due to precipitation events (Oblinger, 2004). Because of the large loads associated with flow peaks and the "first flush," however, additional storm event sampling would probably improve estimates of baseline nutrient loads.

Tetra Tech (2004) has argued that algal concentrations in samples vary greatly due to the grab sampling method, sparse tributary data, and the degree of light penetration in the water column. Better information should therefore be obtained to reduce the uncertainty for each of these concerns. Also, those designing the network should consider the fact that monitoring for NPS pollutants will require more sophisticated equipment to detect changes in smaller increments and at lower limits of detection.

One possible indicator for the assessment of waterbodies impaired primarily by nonpoint sources that has been promoted by Yoder (1995) and the Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction (2001) is biological integrity. Yoder states that measures of biological integrity are more closely linked to some uses than physical or chemical water quality parameters. Moreover, because aquatic biota are so sensitive to environmental changes, biotic indices may register impairment for chemical and physical parameters that may not be monitored or that may not be present at practical detection levels, a problem that has been noted in data for Jordan Lake (Miller, 2004; Tetra Tech, 2004). Several quantitative biological evaluation indices have recently been created or refined, and the state of Ohio has already adopted indicators of biological integrity into its water quality standards (Yoder, 1995).

The Jordan Lake Nutrient Response Model has estimated used the GWLF to estimate nonpoint nutrient loads for 14-digit hydrologic units and identify the units that contribute the largest portions of the total load. The tributaries that contribute the most nutrients to the total Upper New Hope NPS load should be prioritized for additional study. Coordinating these analyses with TMDL development processes for the Upper New Hope Arm tributaries that are 303(d)-listed due to nutrient impairments might increase the amount of resources brought to bear on the nutrient-impairment problem and reduce redundancy in the assessment, planning, and implementation processes.

Analysts who design the detailed subwatershed assessments should study field-scale loading rates for various land uses particular to each subwatershed, using the values used in the GWLF as a preliminary hypothesis with which to test and design further studies. The explanation of how and why the literature export coefficients were modified to become GWLF inputs is not clear in the Jordan Lake Nutrient Response Model documentation (Tetra Tech, 2003). Moreover, data sufficient to calibrate even this fairly basic model is not available for all major tributaries. For example, according to Tetra Tech (2003), Little Creek is not monitored.

Placing a monitoring station at the lowest point of each Upper New Hope tributary will be an improvement that will enable better estimation of the nutrient loads to the lake from each subwatershed. However, even more subwatershed-specific information is needed to reduce other uncertainties, such as the extent that in-stream processes reduce nutrient loads before they reach the lake and how much different land uses contribute to overall loads. Sampling stations and flow gages also need to be placed so as to evaluate whether each jurisdiction is meeting its target load. For database integration purposes, all new data should be spatially referenced, including those collected from volunteer monitoring.

The number of reference monitoring stations may need to be higher initially, especially in major NPS nutrient-contributing tributaries, in order to establish better baseline data on export functions. If funding constrains the necessary number of monitoring units, tributaries could be studied in detail on a rotating schedule. Another ways to help estimate nutrient loads would be to pair watersheds that have similar characteristics for comparison, perform only limited monitoring in one, and extrapolate data to the other. The paired watershed approach can also be used to estimate changes in baseline loads due to land use change or the management strategy (a treatment–response model).

Subwatershed assessments and detailed monitoring plans must be a vital component of the implementation of each Upper New Hope Arm TMDL if the management strategy is to be adaptive in nature. Effectiveness or “success” monitoring is necessary for evaluation of the management strategy. The density of the instream monitoring gages for effectiveness monitoring might vary by number of practices used in a given watershed. Studies should determine what monitoring intensity would be needed to discern a trend due to a given set of controls in a given watershed. To evaluate the effectiveness of a nutrient management strategy, monitoring may be necessary for 5 years or more (USEPA, no date). Due to their longer residence times, evaluating effects of management strategies on lakes may require even more longitudinal data.

As for the lake itself, chlorophyll *a* samples should continue to be gathered throughout the year because winter algal blooms have occurred in the past (CH2MHILL, 2004; Tetra Tech, 2004). Year-round sampling helps determine seasonal effects of nutrient loads in the lake. The most important improvement in the monitoring frequency would be to expand the intensive sampling season to late November so that future models have lower predictive errors for values in late fall and early winter.

Investments in monitoring must be sufficient to avoid, detect, and correct systematic and spurious errors. Poor maintenance of equipment can introduce errors through instrumentation malfunctions or improper exposure conditions, for example, if automatic sampling intakes become blocked over time (Jain and Singh, 2003). Field and data processing personnel must be properly trained so they do not become sources of variation. Station data should be validated with information from nearby stations that is comparable in quality or better. High-priority data or evaluated (secondary) data should be validated using regression analysis or simulation modeling (Jain and Singh, 2003). USGS and NCDWQ already have quality assurance protocols; these should be studied and customized for Jordan Lake nutrient monitoring purposes to ensure that the maximum amount of data gathered are usable.

Funding Activities to Support Adaptive Management

Designing effective local environmental programs is challenging for a number of reasons. Local governments are often lack sufficient staff and equipment. Staff turnover is often a problem, and when staff depart, they take experience and institutional knowledge with them. Political support for environmental programs varies by community and by elected majority. State and Federal governments regularly pass mandates that are unfunded or only partly funded, and macroeconomic trends can have large effects on local economies and tax bases.

As noted by Skupien (1995), sufficient and stable funding of inspections and enforcement activities may be the most important component of a comprehensive inspections and enforcement program. The same is true of a water quality monitoring program. New or enhanced initiatives may necessitate additional staff, training, equipment, materials, maintenance, administration, and recordkeeping. Identifying potential funding mechanisms is therefore one of the most important functions of an implementation plan. Scientific evidence linking watershed and community benefits and pollution control practices will help governments apply for grants and other external forms of funding and respond to objections that additional BMPs will be too costly.

Retrofitting existing development is likely to be the most expensive module in terms of a nutrient reduction per dollar invested. Moreover, jurisdictions can require performance bonds, guarantees, and sureties of new development and redevelopment, but not for existing development. Retrofitting technology is not well developed and the land needed for controls is more expensive in urbanized areas (Miller, 2004). Trading might therefore be a good implementation option for limits on urbanized areas. Recognition of the high cost of retrofitting may also encourage jurisdictions to manage new development and redevelopment more stringently. The Town of Cary has recently done an analysis of the cost of retrofitting existing development; other jurisdictions may find such analyses helpful in crafting cost-effective programs.

The Upper Cape Fear River Basin Association recently won a nationally competitive targeted local watershed grant of almost $1 million from the USEPA that can be used to fund monitoring efforts and other studies. A new branch of the Association may be created, supported only by Jordan Lake jurisdictions with separate pool of funds, to support modeling of Jordan Lake tributaries (Miller, 2004).

Utility fees may offer some relief to those jurisdictions that have or are creating stormwater utilities to meet NPDES requirements. Additional funding may be found through special taxes, dedicated contributions from developer or landowners, or permit fees (Skupien, 1995). Local governments should also explore interlocal partnerships and state and regional resources, especially to implement project-oriented strategies, which might free up funds to enhance ongoing programs.

Conclusions

Adaptive management has currency for water quality planning because it is a process "of continuing inquiry" (NRC, 2001) by which the uncertainty so prevalent in the TMDL process is reduced by a strategically crafted sequence of model design and refinement. The ad-hoc nature of most water-quality data gathering activities has not proved sufficient for complex water quality management purposes. Jurisdictions facing restricted load allocations will need to take the task of designing, implementing, and enforcing NPS programs more seriously if water bodies impaired by nonpoint sources are to be removed from state 303(d) lists.

In any water quality planning process, the jurisdictions involved need a plan to reduce the uncertainties of their particular situation. Such a plan would include an inventory and analysis of existing water quality data, models, and other information that can help planners and managers create a preliminary hypothesis with which to test and evaluate the first attempts at management. It would also include gathering additional data about practices that are already being implemented to reduce impacts from human activities. The stochastic nature of environmental processes means that attempts to evaluate program effectiveness must account for as much non-natural variation as possible.

Before implementation begins, an enhanced water quality monitoring program should be designed and tested so that any needed adjustments can be made prior to the first "experiment." Changes in sample collection methods have rendered too much data questionable and unusable. It is therefore critical to establish monitoring networks and methods with considerable forethought about future uses and assessment needs.

Critical evaluation of implementation efforts is lacking all too frequently in watershed management (USEPA, 2001). Obtaining and disseminating information about water quality improvements will be crucial to adapting future management approaches to face the challenges that arise when managing NPS pollution. Planners and resource managers who use adaptive management to manage water quality will be able to provide better answers to the perennial question, "Who has had that problem in this area, and did the strategy work?" Proper application of the adaptive management concept will enable state and local governments to design future planning efforts armed with more information on which management strategies will be effective and which will not.

List of Abbreviations and Acronyms

BMP	Best management practice
GAO	Government Accounting Office (United States)
NCDWQ	North Carolina Division of Water Quality (Department of Environment and Natural Resources)
NPDES	National Pollution Discharge Elimination System
NPS	Nonpoint source
NRCS	Natural Resource Conservation Service (United States Department of Agriculture)
TMDL	Total maximum daily load
USGS	United States Geological Survey
USEPA	United States Environmental Protection Agency

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Appendix A. Draft Upper New Hope Arm Subwatershed NPS Pollution Management Strategy

Modified from Upper New Hope Arm Subwatershed, Jordan Lake Nonpoint Source (NPS) Pollution Management Strategy (TJCOG, 2004)
N: nitrogen
P: phosphorous

Existing Buffer Protection

- Requires existing vegetated riparian buffers in the watershed to be protected and maintained on both sides of intermittent and perennial streams, ponds, and lakes.
- A total of 50 feet of riparian area is required to be protected on each side of water bodies. Within 50 feet, the first 30 feet, referred to as Zone 1, is to remain undisturbed with the exception of certain activities. The outer 20 feet, referred to as Zone 2, can be revegetated, with certain additional uses being allowed. Specific activities are identified in the strategy as "exempt", "allowable", or "allowable with mitigation". Examples of "exempt" activities include driveway and utility crossings of certain sizes through zone 1, and grading and revegetation in zone 2. "Allowable" and "allowable with mitigation" activities require review by Division staff and include activities such as new ponds in drainage ways and road crossings.
- New buffers are not required to be established unless the existing use in the buffer area changes.
- The footprints of existing uses such as agriculture, buildings, commercial and other facilities, maintained lawns, utility lines, and on-site wastewater systems are exempt.
- Provides buffer mitigation and delegation options.

Agriculture

- All agricultural (including animal operations) and horticultural operations are required to achieve and maintain a net annual N and P load equal to or less than the aerial average allocated to managed land uses. In the Upper New Hope Arm of the watershed, limits for agricultural and horticultural operations are 4.1 lbs./acre of N and 1.1 lbs./acre of P.
- Two levels of committees will be established to assist the implementation of the agricultural strategy.
- A Jordan Lake Watershed Oversight Committee constituted similarly to the Neuse Basin Oversight Committee and responsible for:
  - Developing and implementing a Site Evaluation Tool for evaluating nutrient and phosphorus loadings and reductions from agricultural and horticultural operations within two years after the effective date of the management strategy.
  - Reviewing and approving county/watershed nutrient management strategies.
  - Presenting the above information to the Environmental Management Commission.

(*continued*)

Agriculture (continued)

- Local Advisory Committees (LACs) constituted similarly to the Neuse Basin Local Advisory Committees and responsible for:
  - Conducting the sign-up process for producers.
  - Developing local strategies to meet the county/watershed nutrient management targets.
  - Submitting annual progress reports to the Watershed Oversight Committee.
- Producers are required to register with LACs within one year after the effective of the management strategy. Each LAC is required to develop a local reduction strategy to meet its reduction target within five years after the effective date of the strategy.
- Each producer then has two options:
  - Participate in a collective Local Nutrient Reduction Strategy that provides site-specific flexibility.
  - Implement the Standard Best Management Practices Strategy, including buffers.
- If a LAC does not meet its goal by then, and the producer has not implemented either standard BMPs or site-specific BMPs that are approved by his/her LAC, then this producer will be subject to the BMPs that the EMC decides are needed to meet the LAC's goal.

NPDES Urban Stormwater

- All local governments shall be subject to the NPDES Phase II Stormwater Legislation adopted by the State (S1210), and shall be designated as regulated entities under section 7(3).
- Any local government's jurisdiction within the Upper New Hope Subwatershed shall be considered its regulated coverage area.
- In addition to the requirements specified in S1210, local governments should also comply with the new development and redevelopment, existing development components of the management strategy.

New Development and Redevelopment

- All new development and re-development shall achieve and maintain a net annual N and P load equal to or less than the aerial average allocated to managed land uses.
- In the Upper New Hope Arm of the watershed, the limits are to 4.1 lbs./acre of N and 1.1 lbs./acre of P.
- A Jordan Lake Watershed Oversight Committee will be established and is responsible for:
  - Developing and implementing a Site Evaluation Tool for evaluating nutrient loadings and

reductions from urban land uses.
  - Reviewing and approving the use of the Site Evaluation Tool by local governments.
  - Presenting the above information to the Environmental Management Commission.
- Provides offsite trading options

(*continued*)

Existing Development

- Each local government will analyze its jurisdiction within the Jordan Lake Watershed to determine the stormwater BMPs necessary for its existing development to achieve the nutrient allocations specified in the new development and redevelopment component of the strategy.
- Each local government will prioritize all of the stormwater BMPs that it identified and develop their implementation schedule over a 5-year period. Implementation of retrofits on existing development will occur the next five years.

Nutrient Management

- This component of the strategy applies to persons who apply fertilizer and bio-solid to or manage 10 or more acres of the following types of lands in a calendar year:
  - Cropland (cropland covered by a certified animal waste management plan is exempt)
  - Golf courses
  - Recreational lands
  - Rights-of-way
  - Lawns and gardens in residential, commercial or industrial areas
  - Other turfgrass areas
- Each person affected by this rule must either complete training and continuing education in nutrient management, or develop a written nutrient management plan for all property where nutrients are applied.
- A tax on fertilizer the revenue from which would fund the implementation of this rule.

On-site Wastewater

- Works with DEH to develop programs to control nutrient loads

Forestry

- Works with DFR to require pre-harvest notice
- Considers loading from forest as baseline loading, and uses existing conservation programs

Trading

- Establishes a trading program allowing trading between point source dischargers, point source and nonpoint source, and nonpoint sources

Appendix B. Uncertainty Analysis of the B. Everett Jordan Lake TMDL Watershed Model Development

[Excerpted from the B. Everett Jordan Lake TMDL Watershed Model Development report (Tetra Tech, 2003)]

Watershed models of nutrient loading are inherently subject to high levels of variability, consisting of both uncertainty and natural variability. The natural variability arises because of year to year changes in meteorology, plant/growth cover, and land management. Uncertainty reflects the facts that simulation models are, at best, an approximation of reality, and the parameters of simulation models are not known with a high level of precision. Natural variability, or at least that part of it due to meteorology, is best addressed by simulation over a number of years that provide a selection of different weather patterns. This section focuses on the portion of variability that is due to prediction uncertainty.

The Jordan Lake watershed nonpoint simulation model consists of two basic components: the GWLF model of load generation and the SPARROW model of nutrient delivery. Uncertainty in these two components is multiplicative for nonpoint loads. The SPARROW component also affects the estimation of point source load delivery. Both components are addressed below; however, SPARROW is addressed first, because it affects both point and nonpoint load estimation.

For SPARROW, Smith et al. (2002), in presenting the revised national SPARROW model, provide 90 percent confidence limits on the delivery coefficients, based on bootstrap analysis in which the model is repeatedly fit with random sites deleted from the analysis. For total nitrogen, the 90 percent confidence limits on the delivery parameter is plus or minus 27 percent of the best fit value (for flows less than 1000 cfs). For total phosphorus, the 90 percent confidence limits are plus or minus about 31 percent. The bootstrap confidence limits are actually slightly asymmetric, but the symmetric approximation is close. These estimates can be used to assess the effects of uncertainty in loss rates on model predictions. However, the effect on estimated loads is nonlinear, as the parameter enters into an exponential formulation on travel time.

Application of the bootstrap confidence limits to stream delivery in the Jordan watershed changes estimates of annual average delivered load by approximately ± 3 percent during the calibration period. Thus, the uncertainty associated with loss rate estimates appears small. Significantly greater uncertainty is likely due to errors in estimation of travel time and unmodeled seasonal variation in removal during transport. These sources of uncertainty apply to both point and nonpoint load estimation, as noted above.

For nonpoint load generation, the GWLF model provides a highly simplified representation of actual load generation processes. While GWLF has been widely used, no comprehensive analyses of uncertainty in model predictions are available in the literature. Some information is, however, available from applications to specific sites. Work of Schneiderman et al. (2002) in rural New York state suggests that uncertainty in GWLF predictions of cumulative nutrient load, without modifications to the model, is on the order of 20 percent. However, this uncertainty includes uncertainty in both load generation and transport in a relatively large watershed.

Information on uncertainty in GWLF predictions of nutrient loading for smaller watersheds in North Carolina is available from local model applications (Cadmus, 1995 and 1996). The Falls Lake study (Cadmus, 1995) documents errors in the prediction of four-year cumulative phosphorus loads relative to FLUX analyses of 4.4 percent for Little River and 2.2 percent for Flat River. While these are postcalibration results, the calibration used the same parameters for both watersheds and is thus robust. A good fit was also obtained for total nitrogen in these watersheds, although results for individual months show considerably more variability. In the Cane Creek study (Cadmus, 1996), the error in cumulative loads relative to FLUX estimates over four years was similarly low (9.6 percent for total nitrogen and 0.4 percent for total phosphorus). However, reanalysis of the results shows that the average absolute error of seasonal (3-month) predictions was much larger, amounting to 36 percent of the mean for total nitrogen and 53 percent of the mean for total phosphorus.

These results indicate that GWLF is much better at predicting long-term loads than individual seasonal loads. This arises in large part because of the simplified approach taken in GWLF to sediment, and sediment-associated pollutant, washoff, which is not able to capture the timing of load delivery to streams.

GWLF application for the majority of the Jordan watershed is not calibrated to site-specific observations (although it uses calibrations from watersheds in the area), which will increase uncertainty. It appears reasonable, based on the Cadmus studies, to assume that uncertainty in the estimation of cumulative loads is on the order of 10 percent. The load generation and transport uncertainties are multiplicative. If the transport uncertainty is taken as ± 5 percent, this leads to a range from –14 to +16 percent about the central estimate.

Some further evidence on uncertainty is provided by the comparison of 1996-1998 total loads (point and nonpoint) from the model and FLUX. As noted in Section 6.2.5, error relative to FLUX on annual loads appears to be on the order of ± 10 percent. This results, however, from adjustment of loss rates to achieve a better fit.

Bringing together all these lines of evidence suggests that the total uncertainty on cumulative nutrient loads is likely to be on the order of 20 percent, consistent with Schneiderman et al. (2002). Uncertainty in the estimates of loads for individual seasons is undoubtedly much greater, on the order of about 50 percent. Uncertainty in model estimates of loads for individual years should fall between these ranges.